THESIS PROPOSAL

The New York City Bus Depot

New York, NY

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Executive Summary:

The New York City Bus Depot is a three story building divided into three separate structures. The third structure, C, contains a third floor mezzanine and a high roof structure. This mezzanine level contains office space, and it is currently not connected to a lateral system frame in the East-West direction. Instead, East-West lateral forces are resisted only by posts continuous from the third floor to the high roof. This causes large vibrations under design conditions which can be supplemented by the vibrations of the busses and other large vehicles below.

The building is also designed under seismic design criteria C due to governance of the 2010 New York State Building Code. This allows seismic accelerations to be decreased by 10%, changing the building from what would be a designation of seismic design category D to seismic design category C. For a redesign, it is proposed to ignore the 2010 New York State Code and evaluate the building using 2006 International Building Code provisions alone.

In the proposed solution, the lateral system will be reevaluated and redesigned within seismic design category D. A new lateral system will be design utilizing braced frames in order to reduce vibrations caused by the busses and the potential seismic activity that has controlled the structure thus far. These braced frames will replace those along the exterior walls, and the moment frames in the interior of the building.

This will result in a need for reevaluating the architecture of the building. Relocation of select exterior braces will cause a need for the façade to be studied, and the adjustment of moment frames will cause the bus travel path to be reexamined.

A study of construction impacts will also be necessary, as there will be a change of materials and methods. This change of materials and the increased stiffness of the braced frames could lower the amount of material necessary for the lateral systems of the building. It may also decrease the complexity of the connections. This will result in both cost and schedule changes, both of which will be evaluated.

The following pages present a proposal summarizing the redesign suggested for the New York City Bus Depot. This redesign will be used for study over the Spring 2012 semester. The methods for properly completing this redesign are outlined within the report and include the codes, standards, references, and analysis programs to be utilized. The redesign will rely heavily on the 2006 international Building Code, AISC journal articles and references, Ram Structural System, SAP 2000, and Revit. Tasks for completion are also outlined, which are then combined into a proposed schedule for the semester at the end of the report. The redesign is proposed to be completed by early march and presentations will be held in early April. This thesis will serve as both an academic exercise and a potential practical solution to the lateral framing of the New York City Bus Depot.

Building Introduction (Existing Conditions):

The New York City Bus Depot is a new design-build project that broke ground in June of 2011. This $150 million project is slated for completion in January of 2012. The building site can be seen below in Figure 1 highlighted in red. It is in an area that is currently zoned to be commercial specifically for heavy automotive repair shops that are used for community purposes. The region where this building is to be located was once the place of a river that ran through this part of the city. For this reason, the water table on the site is high and the soil is liquefiable. There is also a portion of the site where there is no solid rock creating a need for piles to be driven down as deep as 150 feet.

Figure 1: Aerial view of the building site highlighted in red. (*Image courtesy of Google Maps).*

The New York City Bus Depot is on a plot of land that is being reused. It was once a former trolley barn in the 1800s and, prior to the most recent demolition, an out-of-date, undersized bus depot that needed expansion for use by the New York City Transit Authority. This new and more environmentally friendly 390,000 square foot bus station will contain facilities for a fleet of 150 busses. The depot will be three stories tall, with each story at an approximate height of 25 feet. On the first floor, facilities will be available for bus refueling, servicing, fare collection, bus washing, and maintenance. The second and third floors will house parking for each of the 150 busses stationed out of the depot. Included in the space will also be offices for employees stationed at the bus depot.

Figure 2: Rendering of the New York City Bus Depot showing its south face and both the corrugated metal and brick veneer facades. *(Image courtesy of STV Inc.)*

Externally, this new facility has a modern appearance with a corrugated metal and brick veneer anchored onto CMU walls as seen in Figure 2. Large, rectangular expanses of windows with aluminum frames help to provide well lit spaces while using minimal electric lighting. The brise soleil that line the tops of the windows on the East façade to control the sunlight entering the building, helping to achieve the most energy efficient performance possible. To pay homage to the vibrant culture of the neighborhood in which the depot is located, artwork will be placed at street level for any passer-by to see. All of these features will help give life to an area of the borough looking to be renewed and revitalized.

In order to be an environmentally friendly facility, the New York City Bus Depot plans to employ green technologies. Two major highlights for this are located on top of the building: a green roof and a white roof. This green roof will help to minimize carbon dioxide emissions (particularly important for such a crowded borough of the city), and the white roof will help to regulate heat gain for the building. Other technologies to be included in the building are a rain water collection system, low emission boilers, heat recovery units, water efficient fixtures, recycled materials, and day-light centered lighting design. In addition to a rain water collection system, a water reclamation system is planned to recycle the water used in bus washing facility. All of these features aim to lead the New York City Bus Depot to a LEED certification upon completion of construction.

Structurally, this building is one which is steel framed. It has unique floor framing due to the multitudes of point loads applied from busses and their towing counterparts. Floors on levels two and three are also ramped like an over-sized parking garage for this bus fleet. Unique loading patterns are also created due to the busses as well as the mixed use occupancy of the building. At the present time, the building is at a 65% submittal stage with its contract documents and more information will be provided as updates are received.

Structural Overview

The New York City Bus Depot is a three story, 80' tall building that rests on piles grouped together with caps scattered throughout the site. The piles are deep due to the site class E classification that indicates the chance for liquefaction of the soil. The building itself can be treated as three separate buildings, as shown in Figure 3, due to the large expansion gaps that separate the framing systems of the building. The first floor consists of a heavily reinforced slab that is 14" to 18" thick for travel by heavy busses and towing vehicles. The framing system consists of heavy steel beams that are designed to resist the loads caused by the traveling busses. On top of each level of this steel framing sits a 6" reinforced concrete slab. This slab is supported by 2" 18 gage metal deck, however this deck is considered as sacrificial and all designs are calculated as though there is simply a concrete deck sitting upon the steel beams.

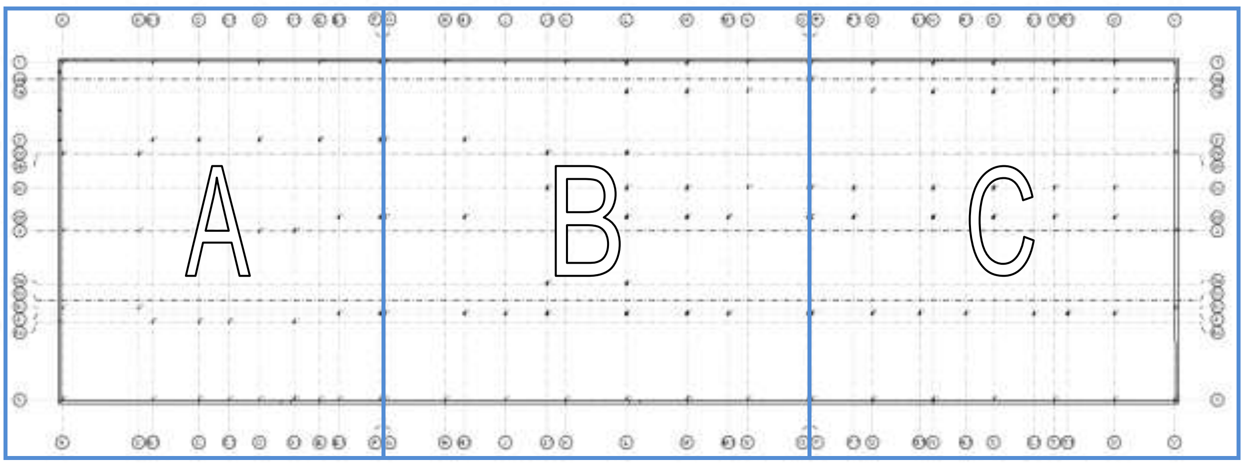


Figure 3: Depiction of the -6" Expansions joints that separate the structure into three distinct structural systems as denoted by the blue boxes. *(Image courtesy of STV Inc.)*

Foundations:

The New York City bus depot requires the use of deep pile foundations due to the site's soil conditions. The site contains layers of organic material that compress under long-term loading, making the site unsuitable to maintain a shallow foundation. Another reason for the pile foundation lies in the liquefaction potential of the soils. Those below the water table, which is about 8' below the site surface, consist of a stratum of sand and a stratum of silt and clay all over weathered rock and bedrock. When tested, it was deemed that these would likely not liquefy during a strong earthquake, but there were some local areas that showed liquefaction potential if the 2500-year event were to occur in the city.

The piles recommended for the site are steel HP12x102 piles that possess the ability to maintain 220 tons (or a service load of 200 tons after subtracting 20 tons of downdrag). These piles are used to support the ground floor structural slabs, columns, and heavy equipment requiring extra reinforcing. They terminate at an elevation 107'-6" above sea level. These piles are required to be driven down to bedrock, which is between 35' and 100' below grade depending on the area of the site. The piles must be hammered into the ground and have a final driving resistance no less than 5 blows per quarter inch of penetration. Also, because of the low pH of the ground water, corrosion effects must be taken into consideration. Due to the effects of this, the piles are to be analyzed for strength at a size 1/8" thinner in the webs and flanges than prescribed. In addition to being able to maintain 200 tons of compression, the piles are to withstand a lateral load of 5.5kips for a single pile and 3.8kips for each pile when analyzed in groups in the pile caps.

Floor Systems:

Two flooring systems are considered in the New York City Bus Depot. On the first floor, there is a slab on grade with a thickness still to be determined. This thickness is to be between 14" and 18" due to the heavy, concentrated loads imposed by the various busses and maintenance vehicles utilizing the facility and the long spans of the slab between piles.

The typical framed flooring system on the second floor, third floor, and third floor mezzanine consists of steel beams and girders supporting a 6" one-way concrete slab on a 2" gage sacrificial composite form deck. This slab on deck is to be reinforced with a rebar layout that yet to be determined on the design drawings. Analysis presented later in this report yields a theoretical value for this reinforcing. The span of this deck is also yet to be determined since the reinforcement has also yet to be determined.

What controls the design of the thickness of the slab is not the distributed load, but instead the point loads induced by the buses. Worst case loadings of the tires of the busses are treated as 4.5"x4.5" squares with the applied point loads dictated in the dead load section of this report. This 4.5"x4.5" square is used in the evaluation of punching shear, which controls the thickness of the slab.

Various beam sizes are used in construction of this structure because of the varying spans, many of which are much longer than the conventional 30 feet bays. Smaller spans under 30'-0" are generally made up of inlay beams of W14s, W16s, and W18s. Larger spans are made of W 24s, W27s, and W30s. Examples of these spans include W27x84s that span 49'-10" and W30x99s that span 55'-6". Girders utilized on these floors include W30s, W33s, W40s, and W44s.

On the west end of the building, ramps are utilized to lead busses to the parking areas on the second and third floors. These are also steel framed with same metal decking described as typical on other areas of the floor. They utilize W24x76s that span the following: 45'-0" on the North and South ends of the ramp and 44'-2" on the West end.

Framing System

The rest of the framing system of the New York City Bus Depot consists of steel columns. They are all W14s with the exception of one W15x655 in a moment frame that supports 1001kips of service dead load and 573kips of service live load. The columns can be expected to support rather large axial loads due to the heavy imposed loads seen in appendix B and the heavy materials.

Lateral System

The lateral system for this building consists of two types of frames: braced and moment. Braced frames flank the interior runs of the ramps on the west side of the building and also run east to west on the exterior lines between column lines O and P as shown in blue on Figure 4. The moment frames are those which run north and south. They are located at column lines F, H.1, J.1, L, M, P.1, Q.1, S, T, U, and V respectively as shown in Figure 4 in orange.

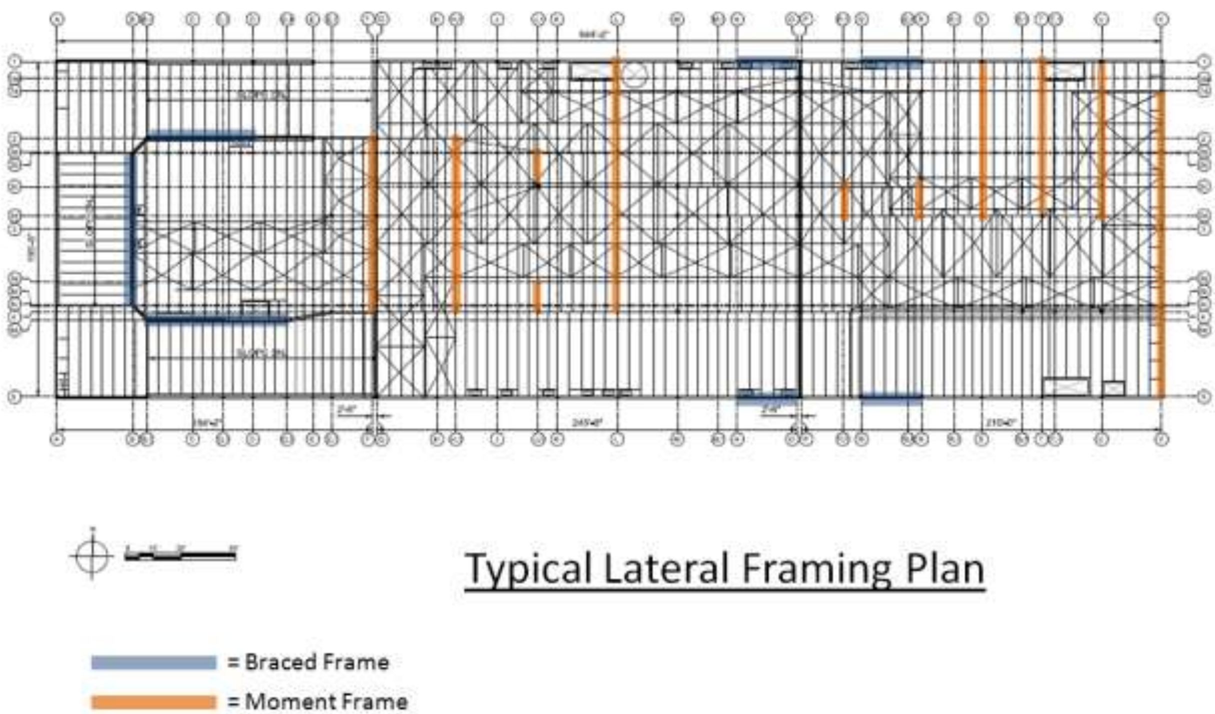


Figure 4: Locations of Moment and Braced Frames. *(Image courtesy of STV Inc.)*

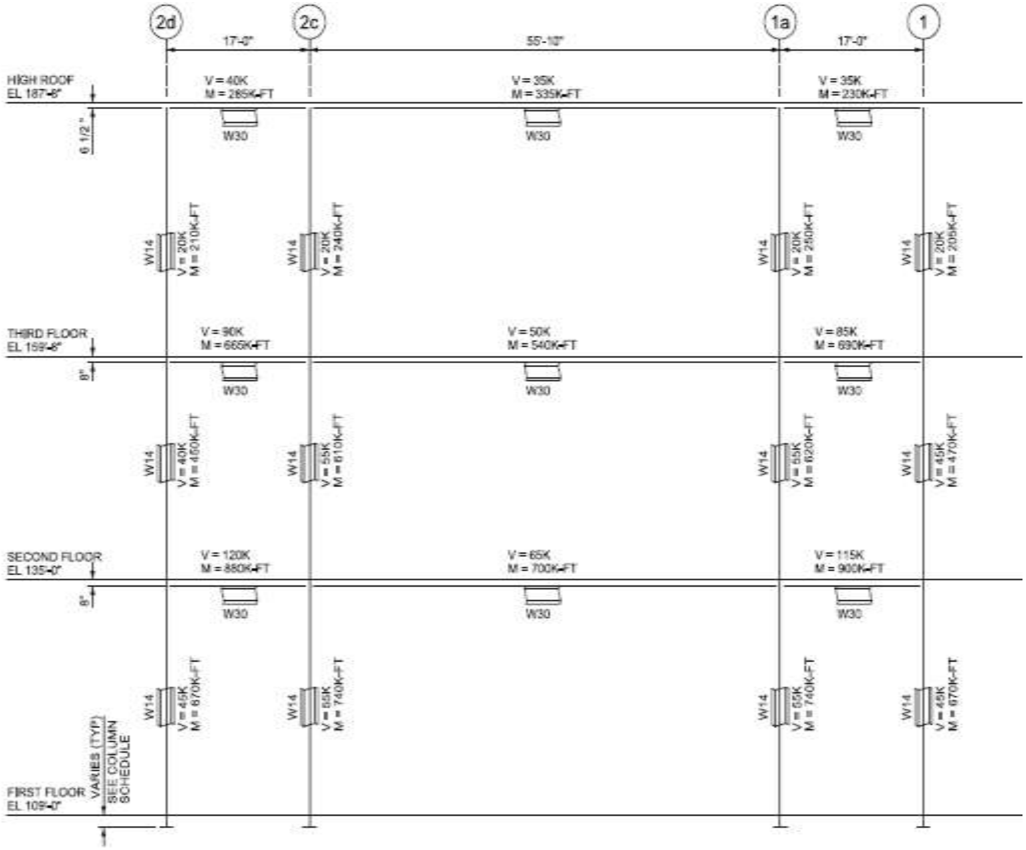


Figure 5: Typical moment frame construction *(Image courtesy of STV Inc.)*

The moment frames are constructed of W14 columns and W30 beams assembled such that the controlling seismic loads may be resisted. The moment frames are required to resist service loads ranging from shears of 5kips along the first floor columns of the frame running along F, to 455kips on the second floor beam along column line V between columns 5 and 3c. These must also resist moments of 1895kip-ft along column line V to 65kip-ft in first-floor column 2F. A typical construction of a moment frame is shown in Figure 5.

The braced frames are constructed of W14 columns of significant weight with W12 members that act as bracing. The diagonal lines that can be seen in Figure 6 show the ramp in the garage. This location, on the west end of the bus depot, is most heavily reinforced with these braced frames due to the vibrations that the walls will have to handle from the traveling busses.

With the exception of one frame, all of the braced frames run from east to west. It is easy to use the braded frames on the west end of the building because there will be no interference with architectural features on the façade there. Windows are in place in the bus parking and office areas to the east, but not in the location of the ramp. Also, on the interior, where these are located will not interfere with bus travel lanes: a key component to the functionality of the bus depot.

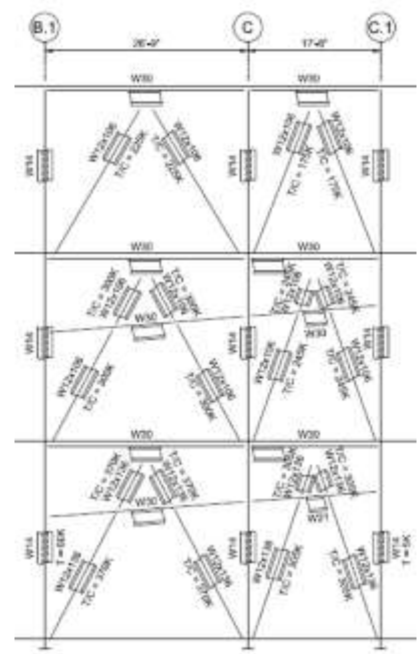


Figure 6: Typical braced frame construction. *(Image courtesy of STV Inc.)*

Roof Systems

The roof of the building is framed similarly to the floors below with respect to size and bay spacing. Certain bays, particularly those above the ramp, utilize smaller W21s because they do not need to be concerned with carrying the weight of the busses. Overall, the roof maintains a similar beam sizing because significant weight is still expected to be carried by the system. The roof will be supporting a green roof as well as a series of air handlers stationed along the north and south edges of the roof.

The decking on the roof will consist of a 4 ½" concrete covering on a 2" 18 gage cold form metal deck. Reinforcement and span for the roof deck/slab system is yet to be determined at this stage of the project.

It should also be noted that the roof has two levels to it. The main roof consists of a diaphragm at 72' and a parapet extending up to 80". The 69' swath of the roof furthest east is actually a bulkhead above the 3rd floor mezzanine where the office space is located. This tops off at a level of 93.' This high level is used in computing wind loads so that the highest factor of safety is considered. See the Wind Load section for more details and Appendix B for calculations.

Design Codes

- 2010 Building code of New York State
    - Adopts 2006 Family of Codes (IBC, IRC, IFC, IMC, IPC, IFGC, IPMC, IEBC) and 2009 IECC
- North American Specifications for the Design of Cold Formed Structural Steel Members "AISI-NASPEC" (Metal Decking)
- 2008 New York City Building Code (Foundations)
- AISC Manual of Steel Construction – Allowable Stress Design, Thirteenth Edition
- Structural Welding Code – Steel (AWS D.1 – Modified by AISC Section J2)
- Details and Detailing of Concrete Reinforcement ACI 315
- Building Code Requirements for Structural Concrete ACI 318-08
- 2008 Building Code Requirements for Masonry Structures (ACI 530-08/ASCE 5-08/ TMS 402-08)
- Specifications for Masonry Structures (ACI 530.1-08/ASCE 6-08/TMS 602-08)

Materials Used (continued on next page)

Material Properties		
Material		Strength
Steel	**Grade**	**fy = ksi**
Wide Flange Shapes	**A992**	**50**
Hollow Structural Shapes	A500, GR. B	46
Plates	A572	50
Pipe Shapes	A53, GR. B	46
Anchor Rods	F1554	36

Sag Rods	A36	36
Welding Electrodes	E70XX	70
Welding Electrodes (Gr. 65)	E80XX	80
Steel Reinforcement	A615	60
Bolts (3/4”-1” dia.)	A325	N/A
Bolts (1-1/8” dia)	A490	N/A
Deck	Gage	
2” Form Galvanized Metal	18	
Concrete	Weight (pcf)	f’c = psi
Formed Slabs	150	5,000
Structural SOG	150	5,000
Slabs on Metal Deck	150	5,000
Foundations	150	5,000
Masonry	Grade	fy = ksi
Concrete Masonry Units	C90	1.9
Mortar	C270, Type M	N/A

Table 1: Material Properties

Gravity Loads:

Dead and Live Loads:

The dead and live load distributions on the floors and roof can be seen in the plans in Appendix B. Tables 2 and 3 respectively compare the dead and live loads utilized in the design with those outlined in the New York State Building Code (2010 Edition):

Dead Loads:

Floor	Distributed Floor Dead Load (psf)	Area (ft^2)	Col. Wt (lb)	Exterior Façade (lb)	Weight per floor (k):
Floor 1	200	125902	502.5	1047696	25682.9
Floor 2	100	125902	922.3	1934208	13512.5
Floor 3	100	125902	622.2	1450656	13212.4
Floor 3 (Mezz)	100	13489.5	30	1128288	1378.95
Roof	100	112412.5	189.9	1128288	11431.15
High Roof	100	13489.5	18.4	564144	1367.35

Table 2: Dead Loads and Floor Weight

In the New York State Building Code, dead loads are dictated to be the actual weight of construction materials. No superimposed loads are suggested in the code, but in this project, they are included. The distributed floor dead load in the chart above does not include these superimposed values. This includes the slab weight and a 15psf beam allowance. Added to this, for total construction weight per floor, is the weight of the columns per floor, and the weight of the exterior façade, which is assumed to be 48psf. The additional superimposed dead loads are 10psf for the first floor; 35psf for the second floor, third floor, and third floor mezzanine; and 95psf for the roves for miscellaneous permanent and semi-permanent equipment such as the air handlers on the roof, maintenance equipment on the first floor, and office materials on the third floor mezzanine.

Live Loads:

Floor	Function	Assigned Live Load (psf)	NYS Code 2010 Perscribed LL (psf)	Notes
Floor 1	Maintenance	250	50	See Chart: Concentrated Loads
	Storage	300	250	
Floor 2	Bus Parking	175	50	See Chart: Concentrated Loads
	Future Shop	250	250	
	Office	150	50	Compact, Versitile
	Vault	600	250	Undisclosed Use
Floor 3	Bus Parking	100	50	See Chart: Concentrated Loads
	Office	150	50	Compact, Versitile
Floor 3 (Mezz)	Office	150	50	Compact, Versitile
Roof	Roof	30	100	Green Roof

Table 3: Live Loads analyzed vs perscriped

The live loads prescribed in the design documents (seen in appendix B) for the New York City Bus Depot are generally close to those dictated in the 2010 New York State Building Code. The reason for some of the larger discrepancies is due to the unique occupancy of the structure. Live loads for bus and truck parking garages are generally defined in linearly distributed loads along lanes and concentrated loads. Table 4 states the New York State Building Code's minimums for bus and truck parking facilities, and Table 5 depicts the concentrated loads expected for the facility by the design engineers. These values are show in tables 3, 4, and 5 respectively

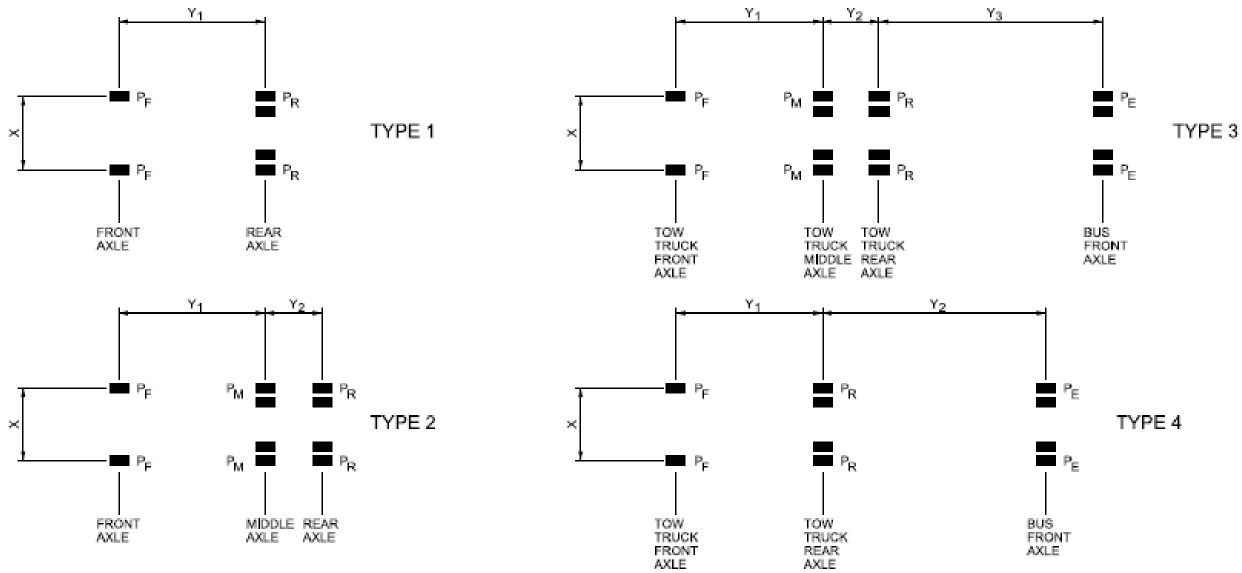
2010 New York State Building Code:
TABLE 1607.6 UNIFORM AND CONCENTRATED LOADS

LOADING CLASS[a]	UNIFORM LOAD (pounds/linear foot of lane)	CONCENTRATED LOAD (pounds)[b]	
		For moment design	For shear design
H20-44 and HS20-44	640	18,000	26,000
H15-44 and HS15-44	480	13,500	19,500

a. An H loading class designates a two-axle truck with a semitrailer. An HS loading class designates a tractor truck with a semitrailer. The numbers following the letter classification indicate the gross weight in tons of the standard truck and the year the loadings were instituted.

b. See Section 1607.6.1 for the loading of multiple spans.

Table 4 *(Image courtesy of 2010 New York State Building Code.)*



CONCENTRATED WHEEL LOAD DIAGRAMS

NOTE: THERE ARE SLIGHT VARIATIONS IN LOAD FOR P_F, P_M, P_R AND P_E, HOWEVER DESIGN IS BASED ON THE HIGHEST VALUE.

CONCENTRATED WHEEL LOAD TABLE

VEHICLE	TYPE	LOCATION	X	Y_1 (DIMENSIONS IN FEET)	Y_2	Y_3	P_F	P_M (LOADS IN KIPS)	P_R	P_E
STANDARD HS20 TRUCK	2	1st, 2nd, 3rd	6.0	14.0	14.0	-	4.0	16.0	16.0	-
MCI 2915 BUS	2	1st, 2nd, 3rd	6.67	26.5	4.0	-	5.7	8.9	4.8	-
ORION HYBRID "NEW GEN" 3877 BUS	1	1st, 2nd, 3rd	6.17	23.83	-	-	6.0	-	11.35	-
VAN HOOL DOUBLE DECKER BUS TD 925	2	1st, 2nd, 3rd	7.17	16.58	4.25	-	5.72	8.91	5.72	-
TOW TRUCK E050-08	2	1st, 2nd, 3rd	7.0	21.67	4.0	-	9.75	8.5	6.6	-
TOW TRUCK E052-03	1	1st	7.0	23.0	-	-	9.9	-	9.1	-
TOW TRUCK E050-08 LIFTING MCI 2915 BUS	3	1st, 2nd, 3rd	7.0	21.67	4.0	45.33	5.57	15.44	15.07	10.08
TOW TRUCK E052-03 LIFTING MCI 2915 BUS	4	1st	7.0	23.0	45.33	-	5.88	-	23.94	10.08
TOW TRUCK E050-08 LIFTING ORION 3877 BUS	3	1st, 2nd, 3rd	7.0	21.67	4.0	39.67	4.31	15.59	15.65	7.77
TOW TRUCK E052-03 LIFTING ORION 3877 BUS	4	1st	7.0	23.0	39.67	-	4.73	-	26.57	7.77
TOW TRUCK E050-08 LIFTING DOUBLE DECKER BUS TD 925	3	1st, 2nd, 3rd	7.0	21.67	4.0	35.67	5.57	15.87	15.45	10.08
TOW TRUCK E052-03 LIFTING DOUBLE DECKER BUS TD 925	4	1st	7.0	23.0	35.67	-	5.88	-	24.69	10.08
OPEN TOP CONTAINER TRUCK	2	1st, 2nd	7.0	9.0	4.5	-	13.0	13.5	13.5	-

NOTE: WHEN TOWED BUS LOADS ARE APPLIED SIMULTANEOUSLY WITH OTHER WHEEL LOADS ON A COMMON MEMBER, TOWED BUS WHEEL LOADS ARE REDUCED BY 25%. SIMULTANEOUS VEHICLE LOADS HAVE BEEN ANALYZED PER THE STALL LAYOUT SHOWN ON THE ARCHITECTURAL DRAWINGS. COMBINATIONS OF VEHICLE TYPES WERE PLACED IN EACH STALL GROUP IN SUCH A WAY TO PRODUCE THE WORST CASE LOADING FOR THE MEMBER BEING STUDIED.

Table 5: Concentrated wheel loads and values *(Image courtesy of STV Inc.)*

Snow Loads

Snow Loads depicted in Table 6 for the New York City Bus Depot are minimal. It is assumed they are included in the distributed Live loads where applicable so no additional calculations were necessary for them. The chart on the right is a display of the design criteria for the snow loading.

SNOW DESIGN CRITERIA
SNOW IMPORTANCE FACTOR 1^{ST} 1.0
OCCUPANCY CATEGORY: I
GROUND SNOW LOAD: 25 PSF
EXPOSURE FACTOR: CS=0.90
THERMAL FACTOR: C1=1.00
FLAT ROOF SNOW LOAD: 15, 75 PSF
SNOW DRIFT LAOD: INCLUDED WHERE APPLICABLE

Table 6: Snow design criteria *(Information courtesy of STV Inc.)*

Lateral Loads:

Wind Loads:

Design Criteria	
Importance Factor (I):	1.0
Occupancy Category:	II
Exposure:	C
Basic Wind Speed (V):	100 mph
Directionality Factor (kd):	1
Topographic Factor (kzt):	1.0
Gust Factor (G):	0.85 (rigid)

Table 7: Wind Design Criteria

Wind loads were calculated to be lower than those provided in the drawings. Not all values were given. Those assumed included topographic factor and GC_{pi} (assumed +/- 0.18 for an enclosed system). Table 7, to the left, is a table of the design criteria used in the analysis. Figures 7, 8, 9, and 10 in this section show the achieved values through calculations shown in Technical Report 2. The values received show that wind is not the controlling factor in the lateral system, but instead seismic forces are.

Wind Pressures N-S Direction										
Type	Floor	Elevation (ft)	k_z (interpolated)	Velocity Pressure (psf)	Cp	Wind Pressure (psf):	Internal Pressure		Net Pressure	
							$+GC_{pi}$	$-GC_{pi}$	$+GC_{pi}$	$-GC_{pi}$
Windward Walls	1st	0	0.85	21.76	0.8	14.80	5.76	-5.76	20.56	9.04
	2nd	26	0.91	23.30	0.8	15.84	5.76	-5.76	21.60	10.08
	3rd	51	1.10	28.16	0.8	19.15	5.76	-5.76	24.91	13.39
	3rd (Mezz)	65	1.15	29.44	0.8	20.02	5.76	-5.76	25.78	14.26
	Roof	79	1.21	30.98	0.8	21.06	5.76	-5.76	26.82	15.30
	Parapet	84	1.22	31.23	0.8	21.24	5.76	-5.76	27.00	15.48
	Bulkhead	93	1.25	32.00	0.8	21.76	5.76	-5.76	27.52	16.00
Leeward Walls	All	All	1.25	32.00	-0.5	-13.60	5.76	-5.76	-7.84	-19.36
Side Walls	All	All	1.25	32.00	-0.7	-19.04	5.76	-5.76	-13.28	-24.80
Roof	N/A	0 to 46.5	1.25	32.00	-0.9	-24.48	5.76	-5.76	-18.72	-30.24
	N/A	46.5 to 93	1.25	32.00	-0.9	-24.48	5.76	-5.76	-18.72	-30.24
	N/A	93 to 186	1.25	32.00	-0.5	-13.60	5.76	-5.76	-7.84	-19.36
	N/A	>186	1.25	32.00	-0.3	-8.16	5.76	-5.76	-2.40	-13.92

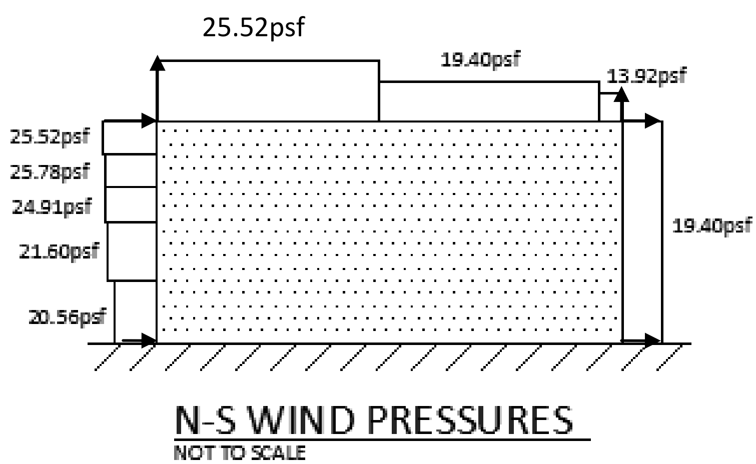


Figure 7: Table stating north-south wind pressures and diagram showing them applied.

Wind Forces N-S								
Floor	Elevation (ft)	Trib. Below		Trib. Above		Story Force (k)	Story Shear (K)	Overturning Moment (k.ft)
		Height (ft)	Area (ft2)	Height (ft)	Area (ft2)			
1st	0	0.0	0.0	13.0	8372.0	172.10	1437.63	0.00
2nd	26	13.0	8372.0	12.5	8050.0	354.74	1265.53	4611.57
3rd	51	12.5	8050.0	7.0	4508.0	312.80	910.80	3910.06
3rd (Mezz)	65	7.0	4508.0	7.0	4508.0	232.43	597.99	1626.98
Roof	79	7.0	4508.0	2.5	1610.0	164.11	365.57	1148.75
Parapet	84	2.5	1610.0	4.5	2898.0	121.71	201.46	304.26
Bulkhead	93	4.5	2898.0	0.0	0.0	79.75	79.75	358.89
							Total Base Shear:	1437.63
							Total Overturning Moment:	133699.95

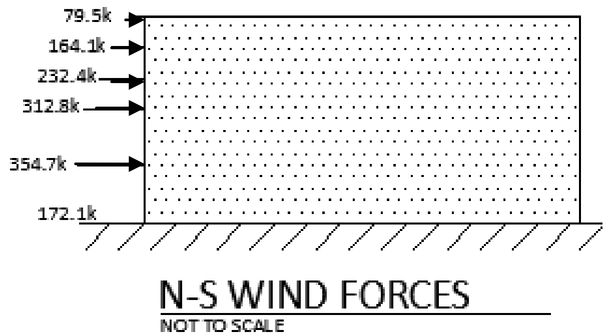


Figure 8: Table stating north-south wind forces and diagram showing them applied.

Wind Pressures E-W Direction										
Type	Floor	Elevation (ft)	k_z (interpolated)	Velocity Pressure (psf)	Cp	Wind Pressure (psf):	Internal Pressure		Net Pressure	
							$+GC_{pi}$	$-GC_{pi}$	$+GC_{pi}$	$-GC_{pi}$
Windward Walls	1st	0	0.85	21.76	0.8	14.80	5.76	-5.76	20.56	9.04
	2nd	26	0.91	23.30	0.8	15.84	5.76	-5.76	21.60	10.08
	3rd	51	1.10	28.16	0.8	19.15	5.76	-5.76	24.91	13.39
	3rd (Mezz)	65	1.15	29.44	0.8	20.02	5.76	-5.76	25.78	14.26
	Roof	79	1.21	30.98	0.8	21.06	5.76	-5.76	26.82	15.30
	Parapet	84	1.22	31.23	0.8	21.24	5.76	-5.76	27.00	15.48
	Bulkhead	93	1.25	32.00	0.8	21.76	5.76	-5.76	27.52	16.00
Leeward Walls	All	All	1.25	32.00	-0.3	-7.34	5.76	-5.76	-1.58	-13.10
Side Walls	All	All	1.25	32.00	-0.7	-19.04	5.76	-5.76	-13.28	-24.80
Roof	N/A	0 to 46.5	1.25	32.00	-0.9	-24.48	5.76	-5.76	-18.72	-30.24
	N/A	46.5 to 93	1.25	32.00	-0.9	-24.48	5.76	-5.76	-18.72	-30.24
	N/A	93 to 186	1.25	32.00	-0.5	-13.60	5.76	-5.76	-7.84	-19.36
	N/A	>186	1.25	32.00	-0.3	-8.16	5.76	-5.76	-2.40	-13.92

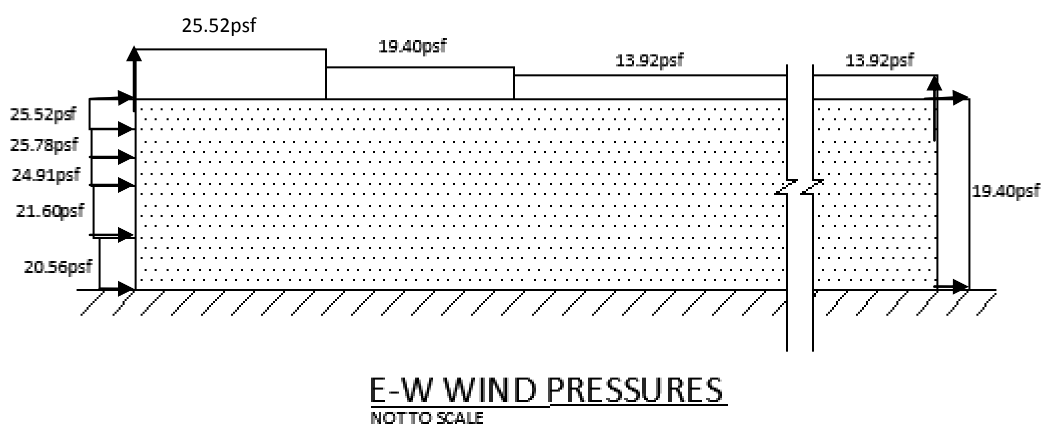


Figure 9: Table stating east-west wind pressures and diagram showing them applied.

Wind Forces E-W								
Floor	Elevation (ft)	Trib. Below		Trib. Above		Story Force (k)	Story Shear (K)	Overturning Moment (k.ft)
		Height (ft)	Area (ft2)	Height (ft)	Area (ft2)			
1st	0	0.0	0.0	13.0	2541.5	52.25	436.42	0.00
2nd	26	13.0	2541.5	12.5	2443.8	107.69	384.18	1399.94
3rd	51	12.5	2443.8	7.0	1368.5	94.96	276.49	1186.98
3rd (Mezz)	65	7.0	1368.5	7.0	1368.5	70.56	181.53	493.90
Roof	79	7.0	1368.5	2.5	488.8	49.82	110.98	348.73
Parapet	84	2.5	488.8	4.5	879.8	36.95	61.16	92.37
Bulkhead	93	4.5	879.8	0.0	0.0	24.21	24.21	108.95
							Total Base Shear:	436.42
							Total Overturning Moment:	40587.48

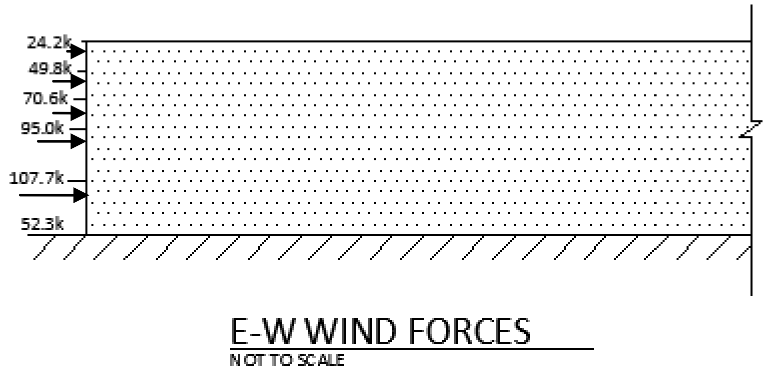


Figure 10: Table stating east-west wind forces and diagram showing them applied.

Seismic Loads:

The following series of charts present in Figures 11, 12, and 13 show a summary of the results of the seismic analysis of the New York City Bus Depot. There are three sets of results for the three buildings that were analyzed separately due to the 6" expansion joint separating them. For the 65% submittal drawings that have been the guide so far, the building was analyzed as one entity, but here, the building is further divided for greater accuracy in consideration of the expansion joints. There are discrepancies between the computer model and the hand calculation shown in the Appendix of Technical Report 3. This is likely due to simplifications made for hand calculations that were not made for the RAM Structural System model.

For further detail on the calculations, see Technical Report 3.

Building A:

Building Dimensions:		
N-S	195.5	ft
E-W:	184.167	ft
Mezz/High F	68	ft
Beam Allow	15	psf

Base Shears		
Direction	C_s	V (k)
(NS)	0.05	1130.33
(EW)	0.053	1198.14

N-S Seismic Analysis

Floor	Distributed Floor Dead Load (psf)	Area (ft^2)	Elevation (ft):	Weight (k):	$w_x h_x^k$	C_{vx}	NS Story Force Fx(k)=CvxV	NS Story Shear (k)	NS Overturning Moment (k-ft)
Floor 1	200.00	36004.65	0.00	7703.43	0.00	0.00	0.00	1130.33	0.00
Floor 2	100.00	36004.65	26.00	4522.76	117591.89	0.22	252.04	1130.33	29388.45
Floor 3	100.00	36004.65	51.00	4222.66	215355.91	0.41	461.58	878.28	44792.52
Roof	100.00	22710.65	79.00	2460.96	194416.22	0.37	416.70	416.70	32919.44
								Total Overturning Moment:	237679.90

E-W Seismic Analysis

Floor	Distributed Floor Dead Load (psf)	Area (ft^2)	Elevation (ft):	Weight (k):	$w_x h_x^k$	C_{vx}	EW Story Force	EW Story Shear (k)	EW Overturning
Floor 1	200	36004.65	0	7703.43	0.00	0.00	0.00	1198.14	0.00
Floor 2	100	36004.65	26	4522.76	210011.28	0.20	235.87	1198.14	6132.61
Floor 3	100	36004.65	51	4222.66	433614.98	0.41	487.01	962.27	24837.28
Roof	100	22710.65	79	2460.96	423165.37	0.40	475.27	475.27	37546.28
								Total Overturning Moment:	68516.17

Figure 11: Building A Seismic Analysis

Building B:

Building Dimensions:		
N-S	195.5	ft
E-W:	210	ft
Mezz/High Roof (EW):	68	ft
Beam Allowance:	15	psf

Base Shears		
Direction	C_s	V (k)
(NS)	0.05	1404.457377
(EW)	0.053	1488.724819

N-S Seismic Analysis

Floor	Distributed Floor Dead Load (psf)	Area (ft²)	Elevation (ft):	Weight (k):	$w_x h_x^k$	C_{vx}	NS Story Force	NS Story Shear (k)	NS Overturning Moment (k-ft)
Floor 1	200	41055	0	8713.5	0	0.00	0.00	1404.46	0.00
Floor 2	100	41055	26	5027.8	130722.8	0.16	223.94	1404.46	36515.89
Floor 3	100	41055	51	4727.7	241112.7	0.29	413.04	1180.52	60206.63
Floor 3 (Mezz)	100	13294	65	1359.4	88361	0.11	151.37	767.48	49886.40
Roof	100	27761	79	2966	234314	0.29	401.39	616.12	48673.16
High Roof	100	13294	93	1347.8	125345.4	0.15	214.72	214.72	19969.28
								Total Overturning Moment:	237679.9002

E-W Seismic Analysis

Floor	Distributed Floor Dead Load (psf)	Area (ft²)	Elevation (ft):	Weight (k):	$w_x h_x^k$	C_{vx}	EW Story Force	EW Story Shear (k)	EW Overturning
Floor 1	200	41055	0	8713.5	0.00	0.00	0.00	1488.72	0.00
Floor 2	100	41055	26	5027.8	233462.21	0.14	204.98	1488.72	5329.52
Floor 3	100	41055	51	4727.7	485475.79	0.29	426.25	1283.74	21738.80
Floor 3 (Mezz)	100	13294	65	1359.4	185762.99	0.11	163.10	857.49	10601.58
Roof	100	27761	79	2966	510006.68	0.30	447.79	694.39	35375.36
High Roof	100	13294	93	1347.8	280865.48	0.17	246.60	246.60	22933.97
								Total Overturning Moment:	95979.22462

Figure 12: Building B Seismic Analysis

Building C:

Building Dimensions:		
N-S	195.5	ft
E-W:	210	ft
Mezz/High Roof (EW):	68	ft
Beam Allowance:	15	psf

Base Shears		
Direction	C_s	V (k)
(NS)	0.05	1404.46
(EW)	0.053	1488.72

N-S Seismic Analysis									
Floor	Distributed Floor Dead Load (psf)	Area (ft^2)	Elevation (ft):	Weight (k):	$w_x h_x^k$	C_{vx}	NS Story Force Fx(k)=CvxV	NS Story Shear (k)	NS Overturning Moment (k-ft)
Floor 1	200	41055	0	8713.5	0	0.00	0.00	1404.46	0.00
Floor 2	100	41055	26	5027.8	130722.8	0.16	223.94	1404.46	36515.89
Floor 3	100	41055	51	4727.7	241112.7	0.29	413.04	1180.52	60206.63
Floor 3 (Mezz)	100	13294	65	1359.4	88361	0.11	151.37	767.48	49886.40
Roof	100	27761	79	2966	234314	0.29	401.39	616.12	48673.16
High Roof	100	13294	93	1347.8	125345.4	0.15	214.72	214.72	19969.28
								Total Overturning Moment:	237679.90

E-W Seismic Analysis									
Floor	Distributed Floor Dead Load (psf)	Area (ft^2)	levation (ft)	Weight (k):	$w_x h_x^k$	C_{vx}	EW Story Force	EW Story Shear (k)	EW Overturning
Floor 1	200	41055	0	8713.5	0.00	0.00	0.00	1488.72	0.00
Floor 2	100	41055	26	5027.8	233462.21	0.14	204.98	1488.72	5329.52
Floor 3	100	41055	51	4727.7	485475.79	0.29	426.25	1283.74	21738.80
Floor 3 (Mezz)	100	13294	65	1359.4	185762.99	0.11	163.10	857.49	10601.58
Roof	100	27761	79	2966	510006.68	0.30	447.79	694.39	35375.36
High Roof	100	13294	93	1347.8	280865.48	0.17	246.60	246.60	22933.97
								Total Overturning Moment:	95979.22

Figure 13: Building C Seismic Analysis

Problem Statement:

The New York City Bus Depot is comprised of a steel framing system that utilizes moment resisting braced frames in the north-south direction and concentrically braced frames in the east-west direction. The twelve moment frames of the system cover long spans are require costly connections. Though this system was deemed acceptable as noted in technical report three, but there may be more efficient and cost effective ways to design the lateral system, particularly if it applies to seismic design category D rather than seismic design category C.

The New York City Bus Depot follows special design requirements due to its location. The new 2010 New York State codes drop seismic accelerations by 10%, allowing the structure to be classified in seismic design category (SDC) C, despite the poor site soil conditions (Site Class E). If the 2006 International Building Code were to govern alone, the building would be classified in seismic design category D.

The current lateral system provides little to no support to the third floor mezzanine, which has a drift significantly greater than that of the floors below. This may particularly be a problem due to the posts attached to the third floor that serve as the sole lateral force resisting elements for the third floor mezzanine and high roof levels of the structure.

Proposed Solution:

The proposed solution for the New York City Bus Depot is to redesign the current lateral system to decrease the cost of connections and, potentially, the number of frames. Systems of braced frames will be compared to the system of moment frames in this analysis for the three separate buildings. Drift will be closely examined, particularly for the third floor mezzanine, which has a story drift above the acceptable amount for non-structural damage according to analysis in technical report three. The braced frames should be able to create narrower, more efficient frames due to their increased stiffness.

These connections require significantly less welding than the moment connections, which should decrease costs for both materials and labor. In addition to this impact in the construction phase of the project, the steel erection process should be expedited, potentially helping to shorten the critical path of the schedule. For these reasons, a construction management breadth will be thoroughly studied as a part of this thesis.

The braced frames will also likely interfere with the open flow of the bus depot. For this reason, the relocation of the braced frames will be assessed and analyzed both structurally and architecturally. The movement of the braced frames in the east-west direction will also have an impact on the façade, which will facilitate a need for a façade study. For these reasons, an architectural breadth will be studied for the bus depot.

If time permits, a study on bracing methods will be conducted. The use of buckling-restrained braced frames (BRBFs) will be compared to the traditional bracing methods in terms of economy, labor intensity, and effectiveness in resisting lateral forces.

Breadth Topics

Architecture Breadth:

Due to the reorganization of the lateral force resisting system, an architecture breadth will need to be studied. The employment of a new lateral system will affect the aesthetics of the building and the flow of traffic within the building. The addition of a braced frame to have continuity from the ground level to the high roof will affect the façade of the building. In particular, glazing will need to be relocated on the north and south sides of the depot. Because of this, a façade study will be done complete with renderings of the depot.

The addition of braced frames within the structure will also alter the traffic patterns within the depot. For this study, knowledge gained from the various studio and architectural design courses will be utilized to adjust the flow within the building. Due to this, there is a potential to have column lines altered, or a revising of the flow diagram of the bus depot.

Construction Management Breadth:

Changing the lateral system on the building will potentially cause major changes to the construction of the building. The braced frames will alter the critical path of the schedule of the building. Use of the braced frames, as opposed to the moment frames, will likely shorten the schedule's critical path due to the lack of elaborate welding necessary for moment frames. The braces are also much less labor intensive, causing a change in the cost on the project. For this, a detailed cost take-off will be performed comparing the changes for costs in labor and costs in materials.

The following will be studied with the alteration of the bus depot's lateral system:

- Changes in Labor Force Required
- Change in Costs for lateral frames
- Change in Critical Path/ Construction Sequence

Information for these studies will be obtained from AE372 course material and outside contacts consisting of field professionals. RS Means will also be utilized for labor rates and materials.

Methods:

The alternate design of the New York City Bus Depot will be examined utilizing the following codes and standards (note absence of 2010 New York State Code):

- IBC 2006
- ASCE 7-10
- AISC Steel Manual (13th edition)
- ACI 318
- Journal articles and design guides

In addition to these resources, computer-aided design programs will be used as well. These include, but are not limited to:

- RAM Structural System
- ETABS
- SAP 2000
- REVIT Architecture
- Google Sketch-Up
- RS Means CostWorks

Structural Solution: Lateral System Redesign

RAM Structural System models of the existing structures in the New York City Bus Depot were created for use in Technical Report 3. This model will be altered to represent the redesigned lateral system, and its results will be compared to those of the model in Technical Report 3. Prior to the remodeling in the RAM model, frames will be modeled in SAP to obtain stiffness values equivalent to those of the original analysis. Various bracing styles will be compared in SAP to find the most efficient style of bracing. Lateral movement, frame stiffness, story forces, story shears, and overturning moments will be compared between the types.

Architectural Solution: Effects of Lateral System Redesign

The lateral system redesign will require both the external façade of the building and the flow within the building to be examined. The location of the frames within Building C will be altered, causing this structure to have the most external alterations. The flow and parking pattern from structures C to A will also be studied for the incorporation of a braced frame within the interior of the structure. Alterations will be dependent on the lateral system redesign. The original and redesigned bus depots will be compared using Revit Architecture and Google Sketch-up.

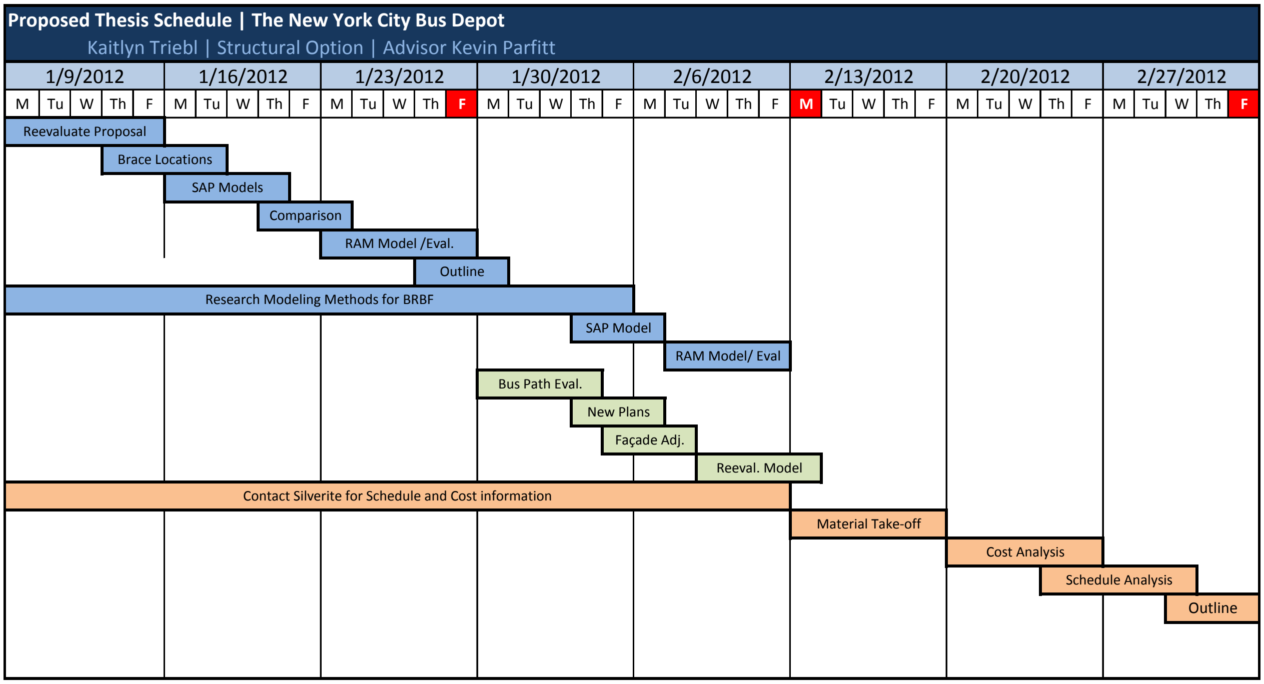
Construction Solution: Effects of Lateral System Redesign

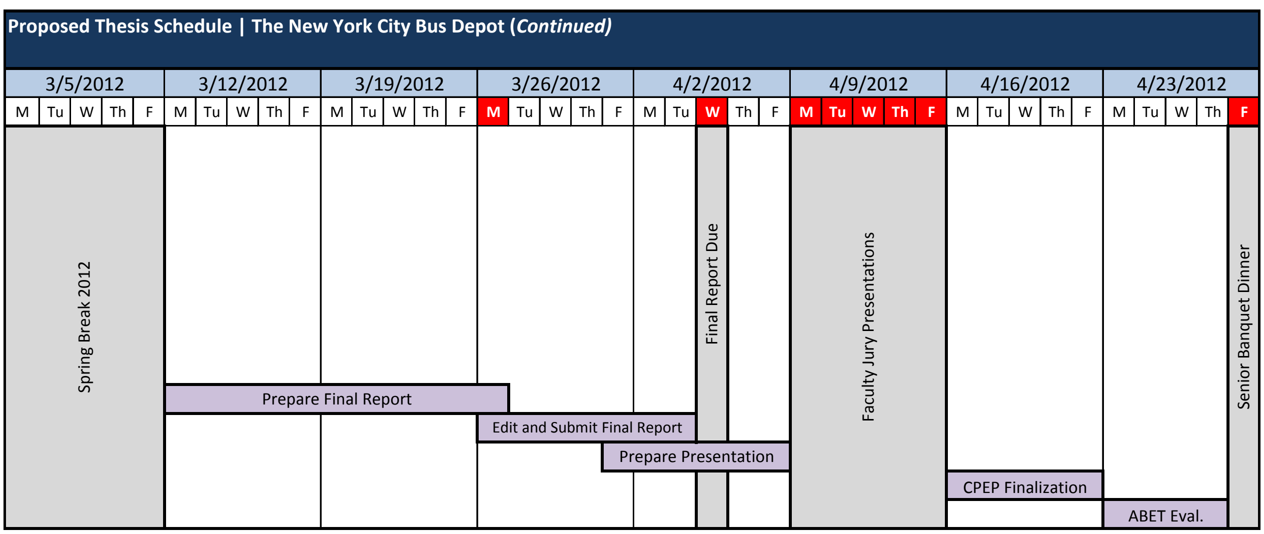
Once the redesigns of the lateral system and façade are complete, the effects on cost and schedule will need to be evaluated. The current contractor, Silverite Construction, will be contacted for information regarding current costs and schedule. From here, points of adjustment will be highlighted and a material take-off, critical path schedule analysis, and cost analysis will be performed. Design information, Microsoft Project, and RS Means will be used for these tasks.

Tasks and Tools:

1. Lateral System Redesign
    a. Recalculate Seismic Loads for SDC D
    b. Assess Proper locations for the braced frames
    c. Create Frames in SAP (Moment, concentric, eccentric, inverted V, and cross-braced)
        i. Determine frame stiffness through application of point load
        ii. Compare with frame stiffnesses to original moment frames
        iii. Reevaluate until equivalent or greater stiffness is achieved
    d. Implement new frames and loads in RAM Structural System Model
    e. Evaluate Model
        i. Lateral Movement
        ii. Story Forces
        iii. Story Shears
        iv. Overturning Moment
        v. Note potentials changes on foundation using building weight
    f. Outline lateral system redesign for final report
2. Architecture Breadth: Façade and Flow Adjustments
    a. Assess New Bus Travel Path
    b. Create New Floor Plan and Flow Diagram
    c. Redesign Exterior Façade and Glazing
    d. Create Rendering and Elevations
    e. Adjust loads in RAM Structural System and Reevaluate if Necessary
    f. Outline Architectural
3. Construction Breadth: Impacts on Critical Path and Cost
    a. Contact Silverite Construction for schedule and cost estimate information
    b. Material and Labor Take-off for
        i. Original Lateral System
        ii. New Braced Lateral System
    c. Cost Analysis Comparisons
        i. Labor
        ii. Materials
    d. Schedule Analysis for Changes in Critical Path
    e. Outline Construction Breadth for Report
4. Compose Final Report
5. Create Final Presentation

Schedule:





Milestone Dates:

1. January 27, 2012: Lateral System Redesign Complete
2. February 13, 2012: Architectural Breadth Complete
3. March 2, 2012: Construction Breadth Complete
4. March 26, 2012: Final Report Prepared
5. April 4, 2012: Final Reports Due
6. April 9 - April 13, 2012: Faculty Jury Presentations
7. April 27, 2012: Senior Banquet Dinner

Schedule Key

- Lateral System Redesign
- Architecture Breadth
- Construction Mangagement Breadth
- Report, Presentation, and Finalizations
- Scheduled Events
- Milestone Dates

Conclusion:

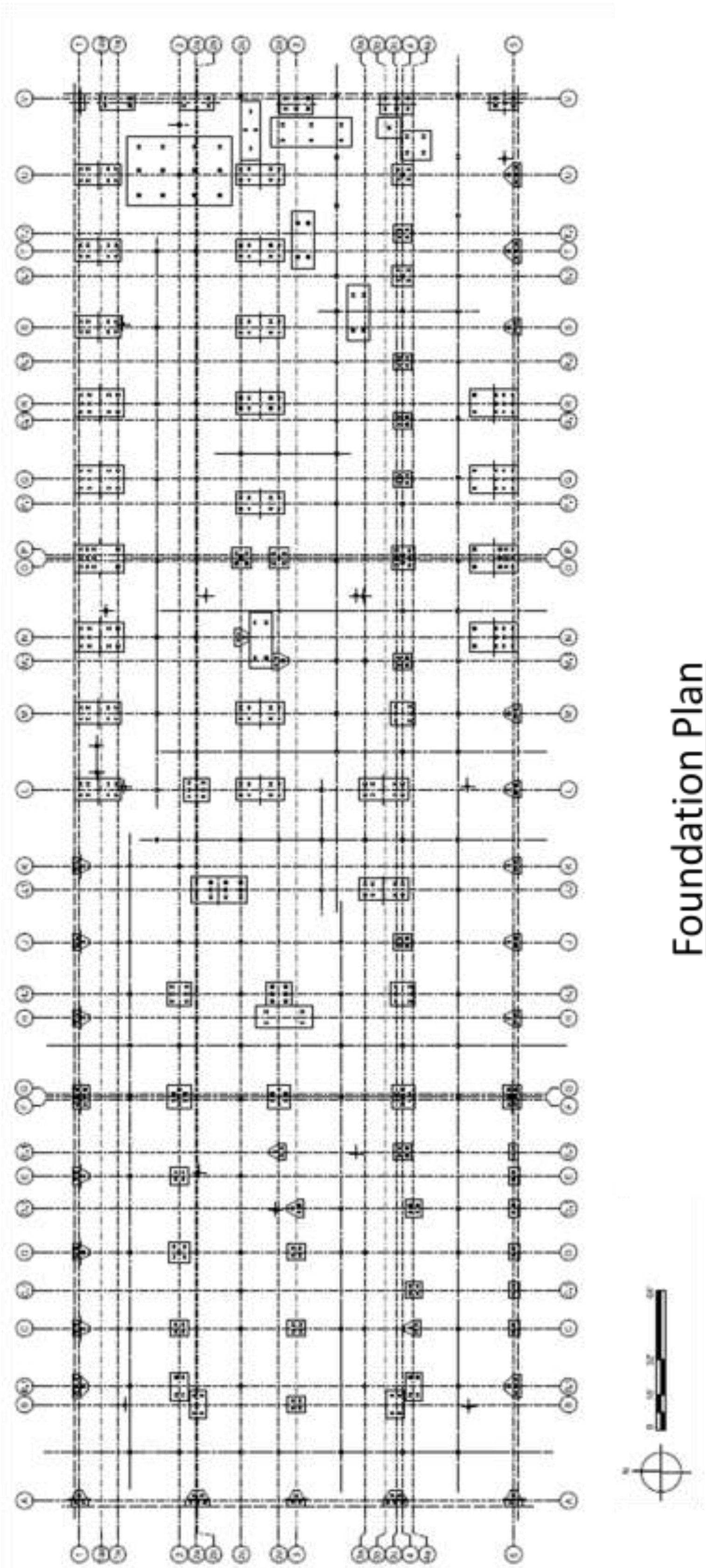
A redesign of the lateral system of the New York City Bus Depot will create a viable solution to lower construction costs and stabilize the third floor mezzanine. A satisfactory analysis of the 2006 International Building Code's parameters for seismic design criteria will also show the standards to which this building would be held in other similar regions. Using braced frames will increase stiffness of the structure which will be necessary in the higher seismic design criteria. They will also reduce the lengths of the frames laterally within the building.

An architecture breadth will show that this lateral system redesign can be done without negatively impacting the architecture of the building. The façade will have alterations, and some changes to the bus flow within the depot will need to be made. The depot will still be fully functional and able to meet the requirement requested by the client.

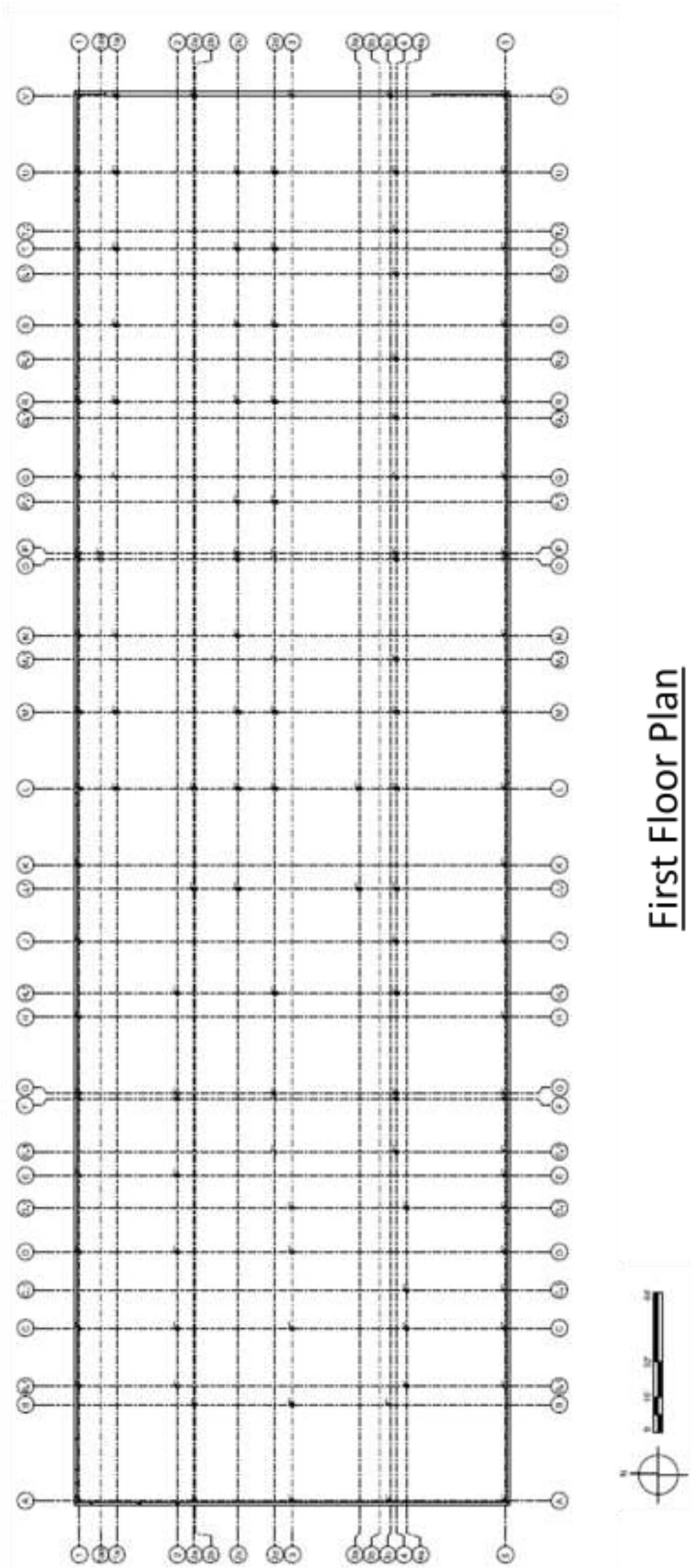
The inclusion of braced frames will have an impact on the construction of the building. The braced frame's addition of material may either complicate the construction or simplify it by decreasing the amount of welding that was necessary for the moment frames. For a thorough analysis, the material take-offs will be assessed, cost analysis for both labor and materials performed, and an analysis of the schedule's critical path conducted.

With thorough research and diligence, the proposed above will be a showcase of what has been learned through years of study in the Architectural Engineering Program, and how that knowledge can be applied beyond the classroom. The project will provide a complete look at a building system's lateral system and each area that it impacts with respect to the building.

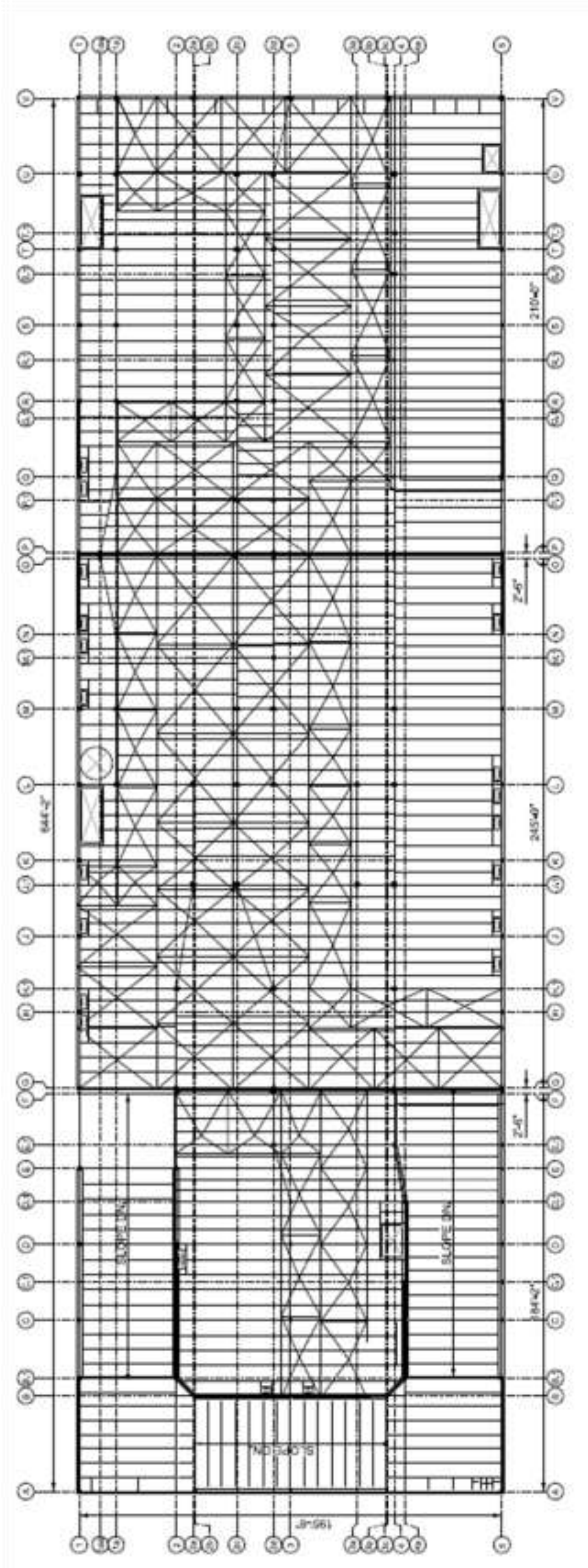
Appendix A: Framing Plans (all images courtesy of STV Inc.)

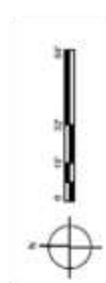


Foundation Plan

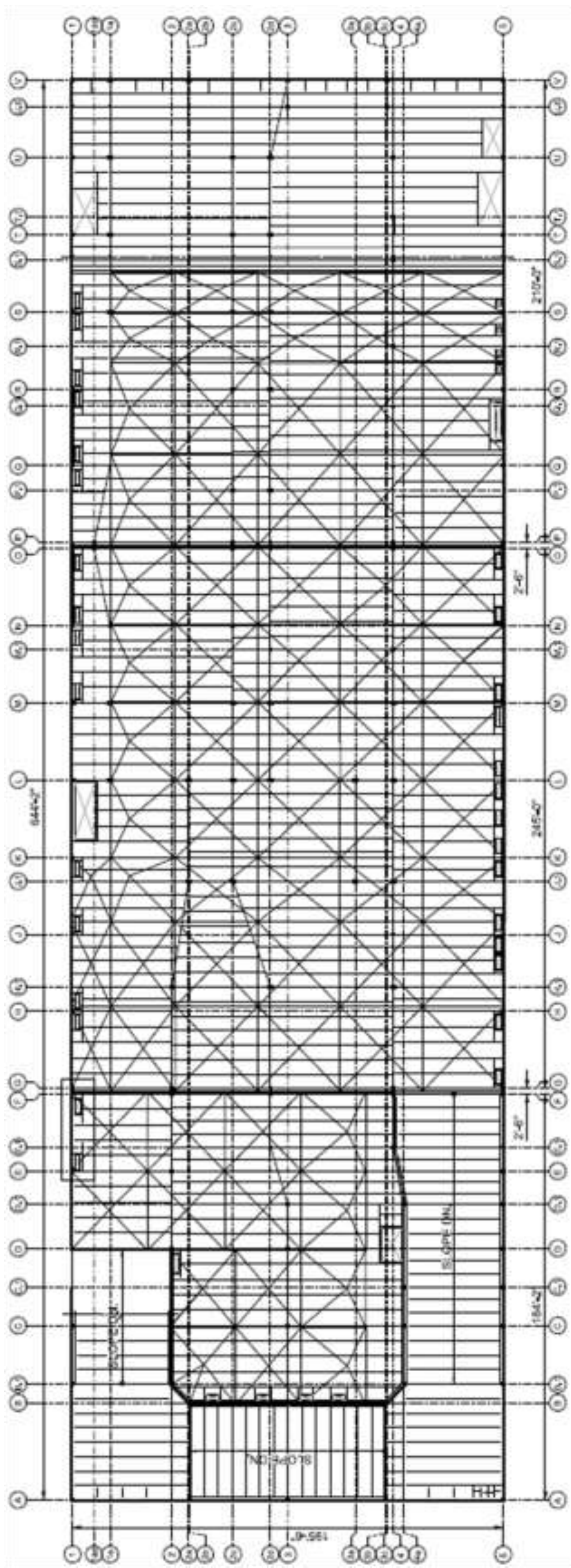


First Floor Plan

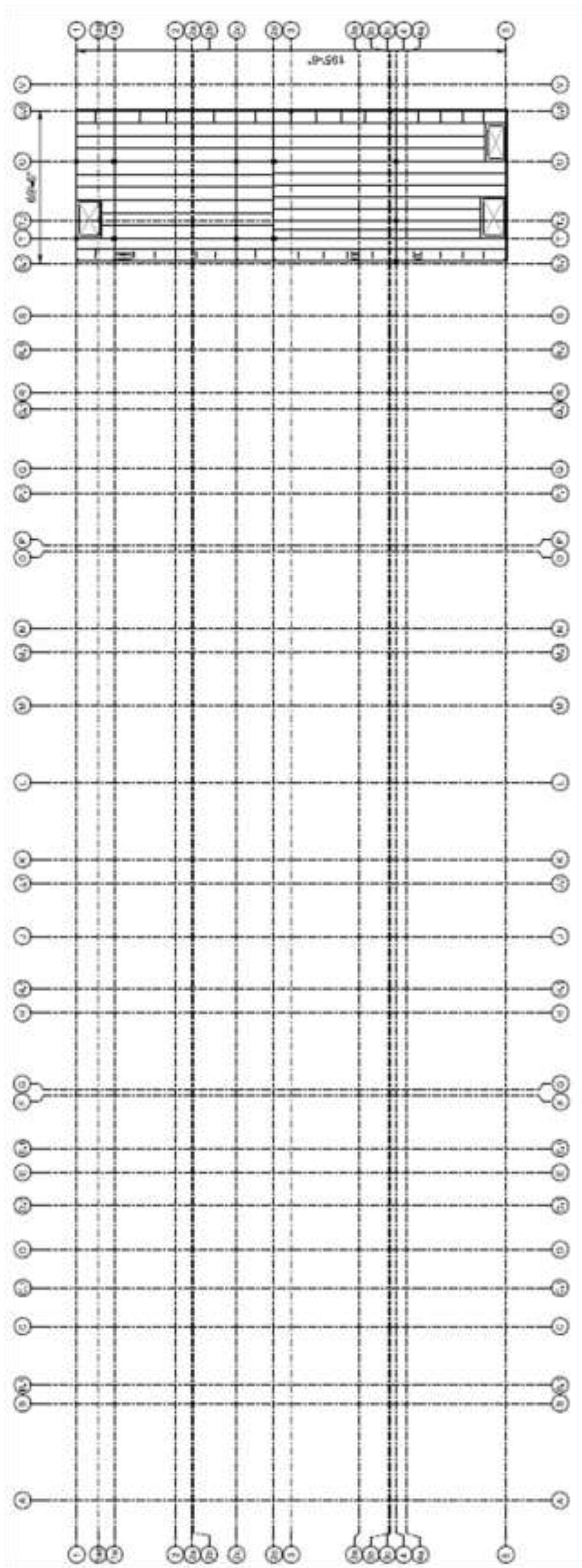




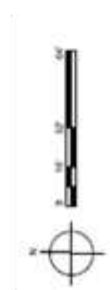
Second Floor Framing Plan

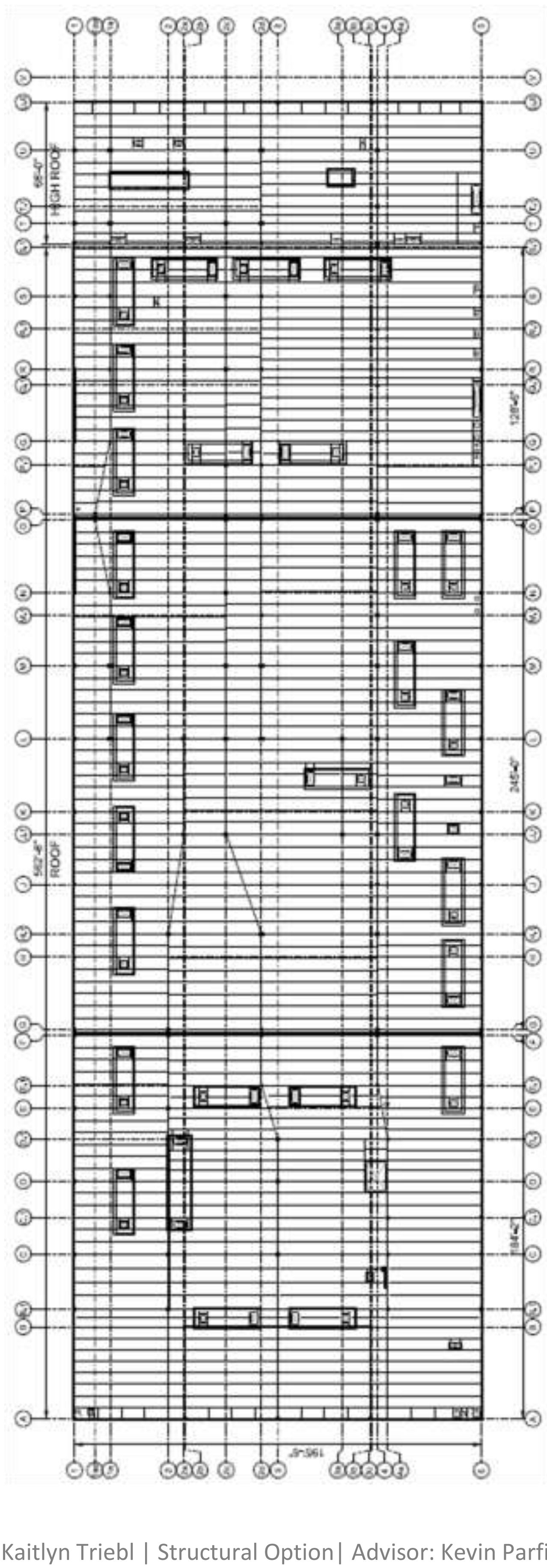


Third Floor Framing Plan



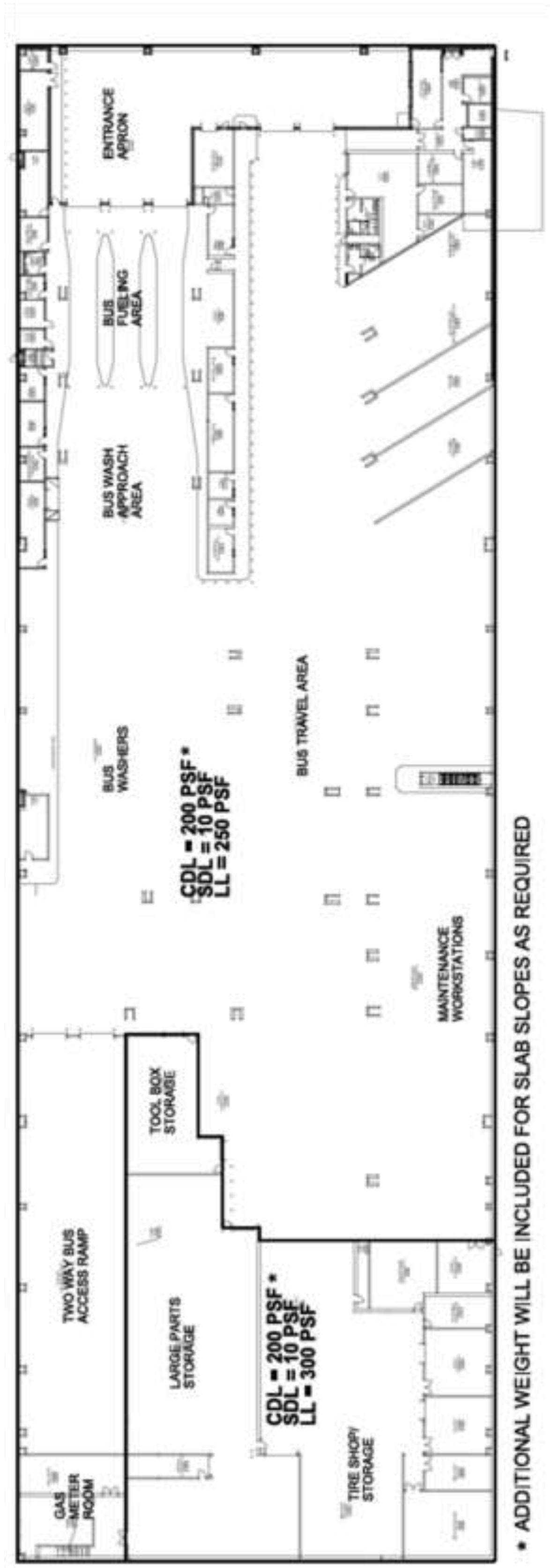
Third Floor Mezzanine Framing Plan



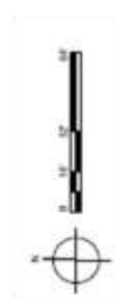


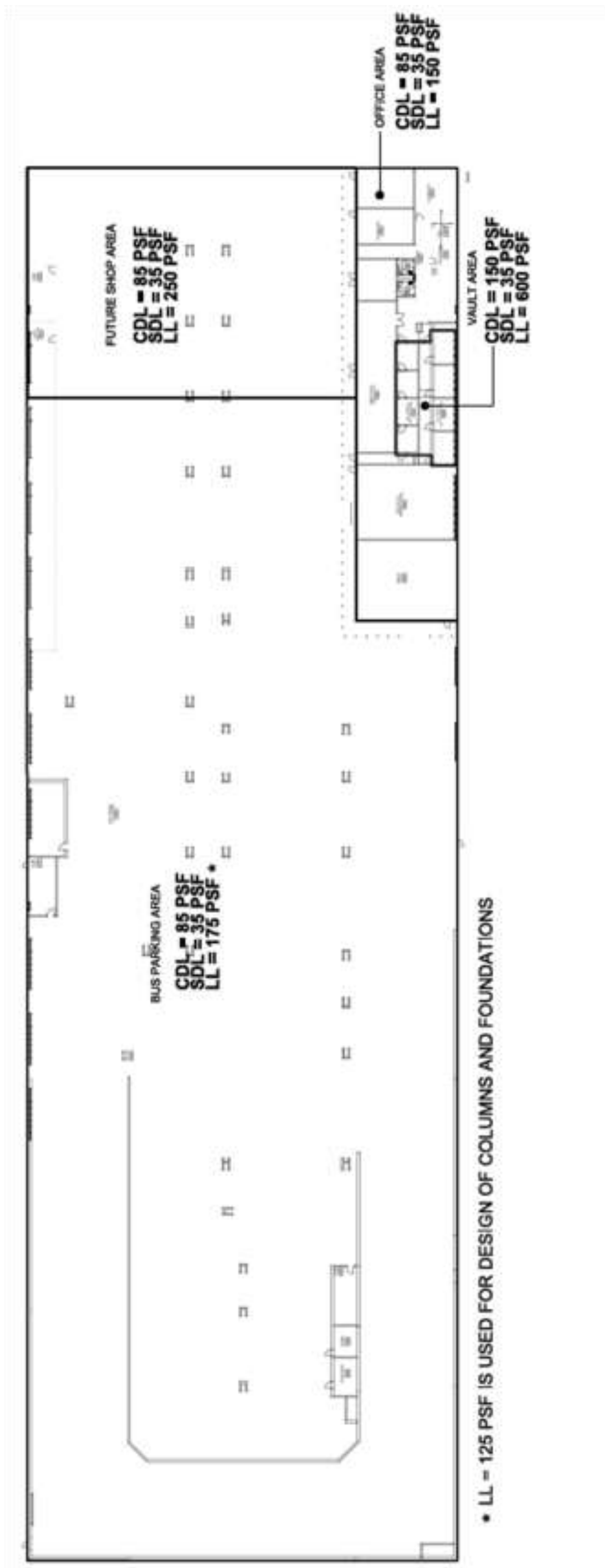
Composite Roof and High Roof Framing Plan

Appendix B: Distributed Loads (all images courtesy of STV Inc.)

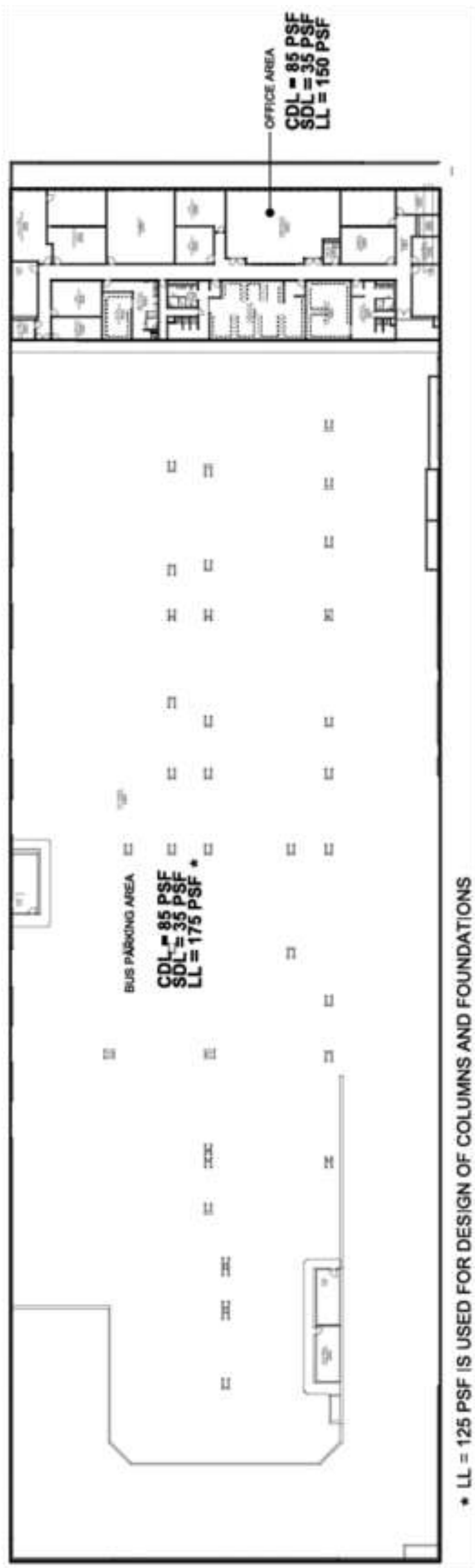


First Floor Load Map

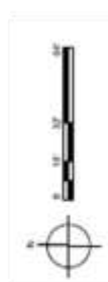


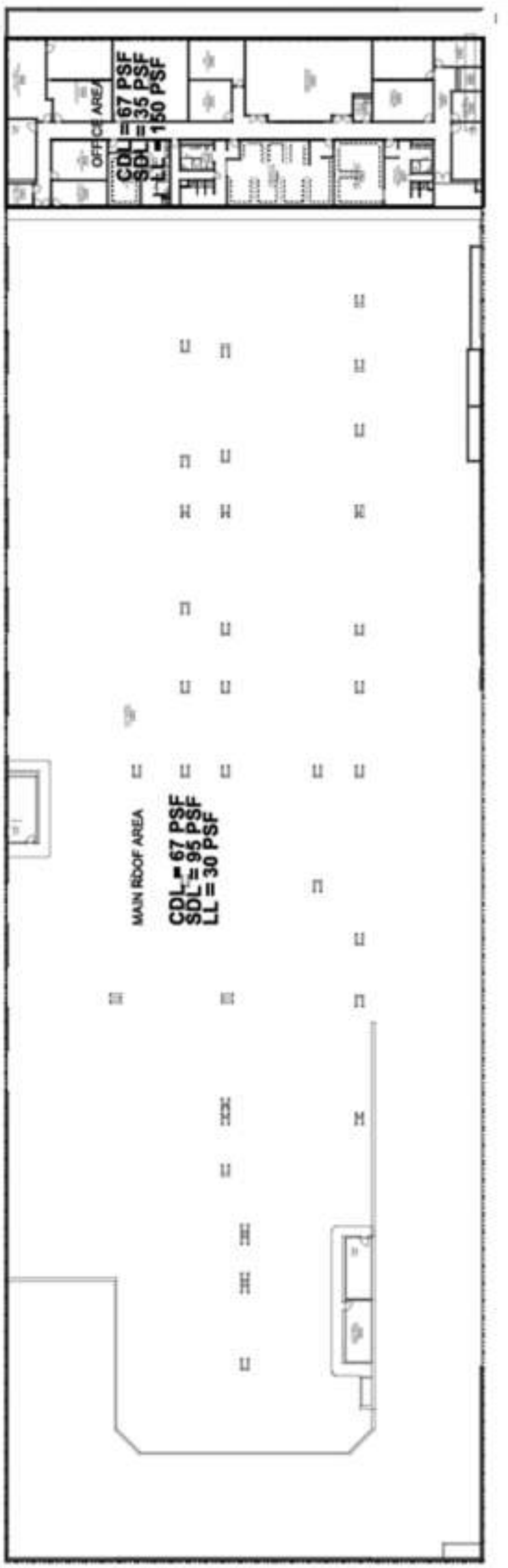


Second Floor Load Map



Third Floor Load Map





Roof and Third Floor Mezzanine Load Map

High Roof Load Map